3.20 Antenna Gain Sensitivity Analysis

The overall function of the antenna is to directionally radiate radar signals and to directionally receive target/clutter/jamming reflected radar signals. The gain of an antenna has a significant impact on radar target detection and tracking performance. Although the antenna gain, near the antenna boresight, has the greatest impact upon radar performance, the off-boresight or side-lobe antenna gain influences the effects of clutter, ECM, and multipath on both target detection and tracking. In radar modeling, it is essential to accurately represent the three-dimensional gain of the antenna at both boresight and off-boresight positions.

The antenna function is modeled as antenna gain, relative to an omnidirectional antenna, as a function of viewing angle off-boresight. The modeled antenna gain pattern and antenna gain resolution are critical subfunctions for a valid radar antenna model.

Antenna gain is often modeled by a mathematical function such as the one shown in equation equation (3.20-1), which describes a uniform (rectangular) aperture distribution:

$$G(\theta) = \left(\frac{\sin k\theta}{k\theta}\right)$$

$$k = \frac{2.7831148}{\theta_b} \tag{3.20-1}$$

where θ = angle, in radians, off-boresight
θ_b = beamwidth

Gain is also modeled as an input table having measured gain values for off-boresight angular increments over orthogonal azimuth and elevation planes.

In ALARM, the user has the option of specifying either a three-dimensional antenna pattern generated by the model from two-dimensional orthogonal slices in azimuth and elevation through the antenna boresight, or a full three-dimensional digitized gain pattern. For either type of pattern, the model requires input elevation and azimuth antenna gain values at increments specified by the user, but limited by model dimensions to 0.1° steps (or greater). The antenna gain in a particular direction is determined by finding the off-boresight azimuth and elevation angles of the random point in space of interest. This point may represent the target, a terrain patch, or a stand-off jammer. For a 3-D gain pattern, a simple look-up in the array containing the pattern yields the gain for the specified aspect. For a 2-D pattern, the antenna gain is determined by first computing the off-boresight azimuth and elevation angles in the direction of interest. The antenna gain at the off-boresight angle of interest is then calculated as the product of the elevation and azimuth gains at the respective off-boresight angles:

$$G(\theta,\varphi) = G(\theta) \ \ G(\varphi) \qquad (3.20\text{-}2)$$

where θ = azimuth angle, in radians, off-boresight
φ = elevation angle, in radians, off-boresight

The digitized 3-D pattern most accurately represents the gain function, but good data may be difficult to find. The 3-D patterns derived from 2-D antenna gain parameters using equation equation (3.20-2) accurately simulate the gain of antennas having rectangular apertures. However, 3-D patterns interpolated from 2-D patterns for other kinds of antenna apertures normally associated with operational radars do not accurately simulate the off-boresight gain.

3.20.1 Objectives and Procedures

Two different sensitivity analyses are conducted for this FE. The first assesses the impact of using three-dimensional antenna patterns derived from two-dimensional data, rather than actual three-dimensional antenna patterns; this is the FE-level analysis. The second evaluates the impact of antenna gain resolution on the computation of signal, clutter, and maximum detection range; this is the model-level sensitivity analysis.

At the FE level, the measure of effectiveness (MOE) used to determine sensitivity is a greater than 3 dB change in normalized antenna gain when comparing the modeled 3-D pattern with the perfect pattern. At the model level, the MOE is a 5% change in normalized mean target detection range when comparing the test cases with the baseline case.

The sensitivity analysis procedure for comparison of interpolated 3-D and “perfect” 3-D patterns is:

1. Use ALARM to compute a 3-D antenna gain pattern based on the following conditions:

    a. Number of slices through boresight = 1 at 45.0˚

    b. Resolution = 0.1˚

    c. Antenna beamwidth = 1.0˚ (symmetrical)

    d. Antenna pattern based on equation (3.20-1)

2. Compare the ALARM-generated antenna pattern with a perfect pattern.

The sensitivity analysis procedure for gain resolution is:

1. Run ALARM for varying antenna resolutions for the following conditions:

   a. Antenna gain based on equation (3.20-1)

   b. Resolution = 1.0˚, 0.5˚, 0.1˚, and 0.01˚

2. Compare initial detection range plots and statistics.

For these model runs, the ALARM code was modified to support the increased number of antenna resolution data points. This modification involved increasing the variable MAXAZEL to 18,000 from the standard 3,600. MXAZEL specifies the maximum number of azimuth and elevation entries allowed in the DATAGANR and DATAGANT ALARM data input decks. (These input blocks specify the receive antenna gain and transmit antenna gain, respectively.)

Table 3.20-1 identifies the specific parameters varied, and the output variables recorded, during each ALARM run.

Table 3.20-1 ALARM Runs for Antenna Gain Sensitivity Analyses

Sensitivity Parameter	Analysis Level	Input Variable	Range of Variation	Output Variable	Test Case Description
2-D vs 3-D Patterns	FE	DAZTXD DELTXD or DAZRXD DELRXD	**“perfect” 3-D pattern**, 2-D pattern	TGTABL or RGTABL	An off-line driver is used to call ALARM subroutines to generate 3-D antenna patterns using a sinx/x function (“perfect” pattern) and interpolation from 2-D data. The patterns are then visually compared.
Gain Resolution	Model	DAZTXD DELTXD or DAZRXD DELRXD	**1.0**, 0.5, 0.1, 0.01 degrees	TGTABL or RGTABL	ALARM is run in Contour Plot mode, using the 4 values for antenna gain resolution. Initial target detection range is measured at each flight path waypoint, during each model run.
Note: Values in **bold** indicate baseline case.					

3.20.2 Results

2-D vs 3-D Patterns: The ALARM algorithms for determining off-boresight antenna gain will induce an error for some antenna types. Figure 3.20-1 shows the theoretical antenna gain for a 45.0˚ slice through the orthogonal axis for an antenna having $((\sin x) / x)^2$ gain characteristics. Figure 3.20-1 also shows the comparative antenna gain plot derived using the ALARM algorithm. As can be observed, there are significant differences in the comparable antenna gain patterns which are likely to impact the calculations of clutter or stand-off jamming signal returns.

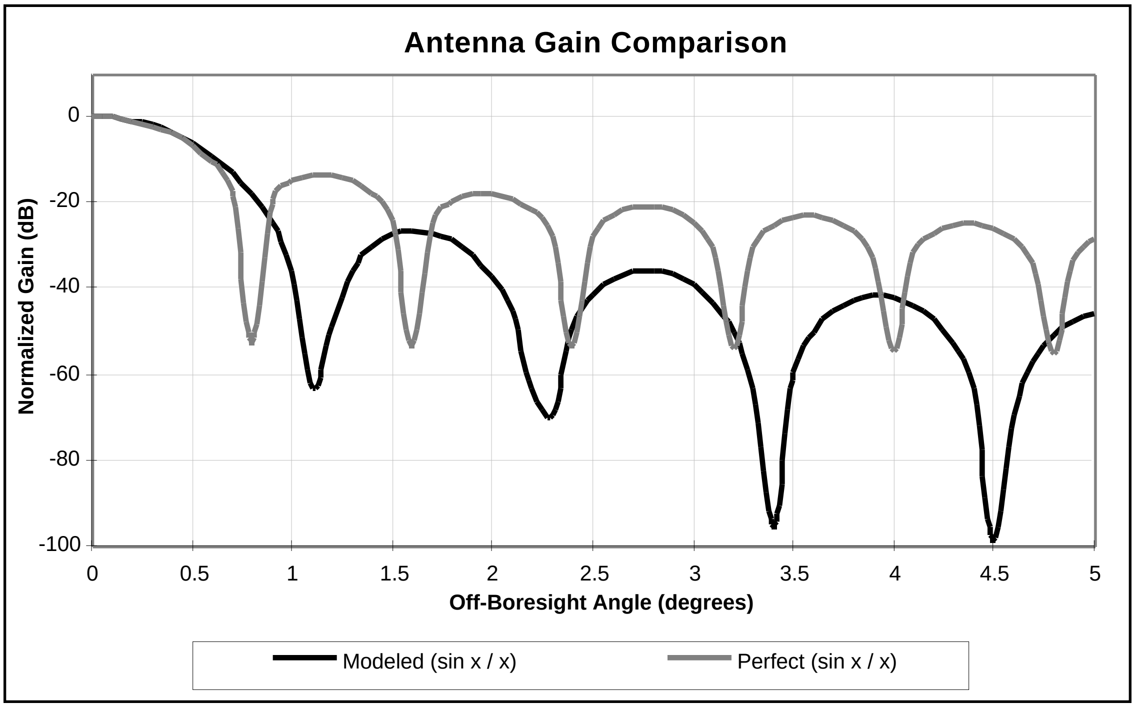

Figure 3.20-1 Antenna Gain Comparison

Gain Resolution: As shown in figure 3.20-2 and table 3.20-2, there are no differences in initial detection range for the various changes in antenna gain data resolution.

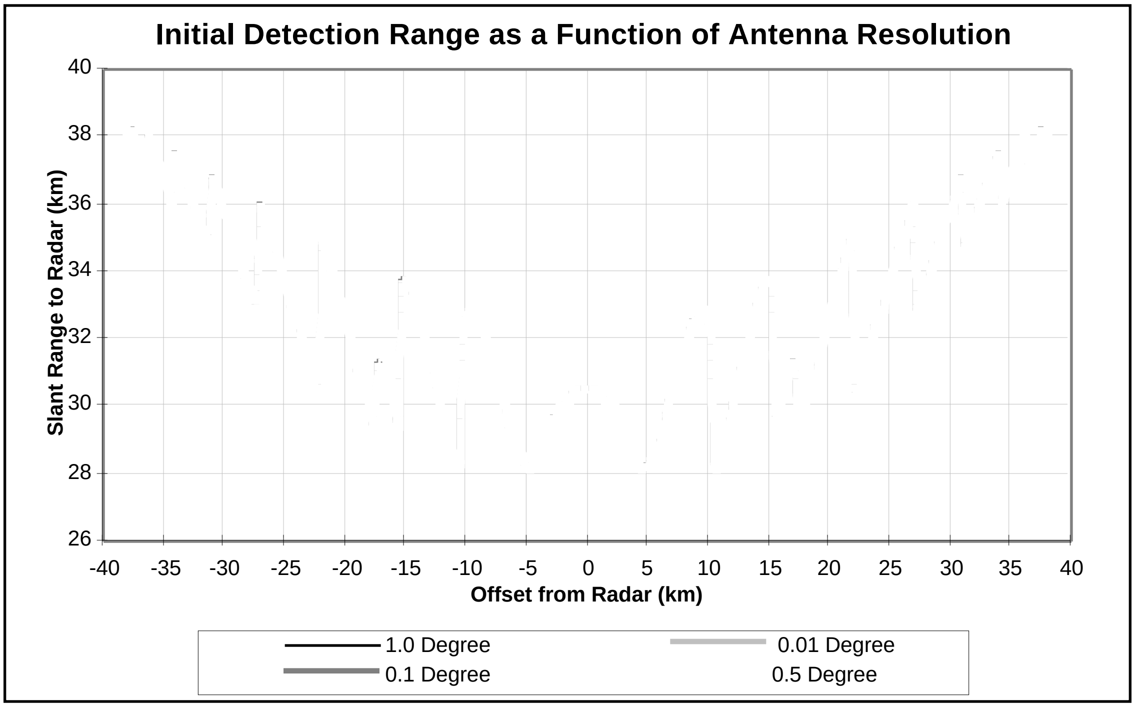

Figure 3.20-2 Initial Detection Range for Antenna Gain Sensitivity as a Function of Antenna Resolution

Table 3.20-2 Detection Range Variance as a Function of Antenna Resolution

Antenna Resolution	Mean (m)	σ (m)	Normalized Mean Difference	% Change
1.0˚ (Baseline)	32.73	2.87	-	-
0.5˚	32.73	2.87	0.000	0
0.1˚	32.73	2.87	0.000	0
0.01˚	32.73	2.87	0.000	0

3.20.3 Conclusions

2-D vs 3-D Patterns: The sensitivity analysis was limited to a single antenna type having a $((\sin x) / x)^2$ gain response and a beamwidth of 1.0˚. However, the gain comparison shown in figure 3.20-1 indicates significant differences in off-boresight gains. It is apparent that actual 3-D antenna gain patterns should be used when available, particularly in high-clutter and side-lobe jamming environments.

Gain Resolution: ALARM assumes perfect pointing at the target. Sensitivity analysis results indicate that ALARM is insensitive to changes in antenna resolution for the perfect pointing assumption. However, it should be noted that without perfect pointing, in a high-clutter or SOJ environment, antenna resolution could be a more significant factor.